The neural basis of consciousness and its capacity in brain waves

Probably the most obvious and important observation about working memory (the ability to hold things "in mind") is how limited it is. It is difficult to think about multiple things simultaneously (e.g., email and talk on the phone), an annoyance to would-be "multi-taskers." But in fact this limit on thought may be characteristic of -- or essential to -- high-level brain function.

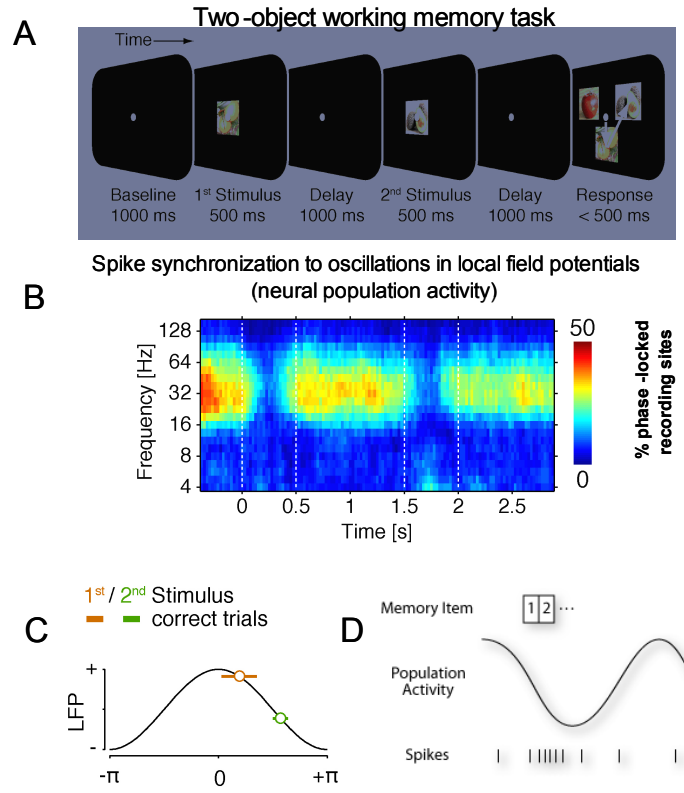

Fig. 1. **A**. Monkeys remembered a sequence of two successively presented target objects. After a memory delay, the monkeys were shown an array of three different test objects and had to report they remembered the two target objects by making eye movements to them in the order of their initial display. **B.** Time-frequency representation of spike-LFP oscillatory synchronization. **C.** Information about the two remembered objects as a function of the LFP phase. **D.** Schematic representation of memory slots for the two objects.

A project at the NSF-funded CELEST Science of Learning Center is addressing this and we have obtained a key insight. At Earl Miller's lab at MIT, we discovered that in monkeys, information about two objects held in working memory is linked to different phases of brain waves (Figure 1). The firing of individual neurons (i.e., "spikes") synchronizes to the waves so that the discrete neural signals ("spikes") carrying information related to one object occurred at one phase of the wave, and spikes related to the other object occurred at a different phase. In other words, the brain waves seemed to provide different "memory slots" for each of the two remembered objects.

This is a previously unknown form of neural coding that may explain why consciousness has a severe capacity limitation: there are a limited number of memory slots per wave.

Siegel, M., Warden, M.R., and Miller, E.K. (2009) Phase-dependent neuronal coding of objects in short-term memory. *Proceedings of the National Academy of Sciences*, 106: 21341-21346.